THE PERFORMANCE OF A HARRINGTON FORCED DRAFT CHAIN GRATE STOKER

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A THESIS

PRESENTED BY

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INTRODUCTION

The chain grate type of stoker is the most extensively used in the Middle States to-day. Its general ruggedness and symplicity of operation makes it desirable in those power plants where ordinary operating crews are employed. In the Eastern States where intense rates of combustion are maintained, the under-feed type is preferred because of its ability to withstand clinker formation, and also its greater adaptability to forced draft control. A preliminary study of chain grate design would bring one outstanding difficulty to mind; namely, that of air control. Practically all inefficient boiler plants are such, because of air leakage and poor mixing of the gases in the combustion chamber. Many attempts have been made to remedy these difficulties, but the solution has not

as yet been found.

It has often and truly been said that a good engineer must of necessity be a good guesser also, and this is undoubtedly true of the power plant engineer. Two boilers and settings of the same make and to all out-ward appearances identical, often give quite different operating efficiencies. This is due to unknown factors which in practical work cannot be considered.

Poor efficiency is the general result when boilers are run considerably under or over rating. Boiler manufacturers have found from experience that for a certain number of square feet of heating surface their is a definite amount of grate area required. In other words the ratio between heating surface and grate area is fixed. Therefore, when a plant is operating at half rating, the grate area is twice as large as that required for correct operation; and vice versa, when running at twice rating the grate area is only half the theoretically required. In order to appreciate more fully the influence

of grate area on efficiency it will be necessary to study somewhat the manipulation of the chain grate. There are two general methods that can be used to meet varying load requirements; namely, regulation of the fuel bed depth, and the speed of grate travel. It is obvious that capacity is a direct function of the depth of the fuel bed, but the depth of fuel bed depends on the kind of coal burned and also the available draft. Since most power plants operate on natural draft and have a practically constant available head, the depth of the fuel for any one coal is usually constant. Therefore, regulation is most generally obtained by varying the rate of grate travel.

The coal travels from the back to the bridge wall where it is dumped into the ash pit. The space between the grate surface and the bridge wall must be sufficiently great to take care of the ash at maximum capacity. If this were not done it would be impossible to dispose of the refuse at forced ratings and serious damage would likely result. Once this distance

is determined and fixed, it is not readily changed. The result is that under light loads and with a coal low in ash, a considerable gap is left between the wall and the dumping refuse. This air space forms a splendid short circuit for the draft and is the chief reason why many of our so-called modern installations must run with from 200 to 300% excess air to keep their stacks clear.

Another disadvantage of running under rating is that at least half the grate surface may be dead. That means that the coal is burned to ash by the time it is half way to the bridge wall and close inspection will generally show that much of the air is forcing its way thru the thin layer of ash rather than thru the coal.

The chief loss in grate efficiency encountered when running over rating, is that of dumping live coal. Speeding up the grate is in effect hurrying the cycle of operation thereby allowing a shorter period of time for complete combustion of the coal.

The result is that if the fireman neglects to carefully watch his fire the percent of combustible in the ash may be greatly increased.

Thus as a summary it may be said that for best efficiency there should be first; a uniform depth of fuel, second; even and complete combustion just before dumping, and lastly; a minimum short circuit of draft in front of the bridge walls.

Preparation for the Test.

Before conducting any of the tests it was necessary to calibrate the instruments to be used. Included in the regular boiler room equippment is a Bailey feed water meter and recorder. It is of the venturi type and gives a record of the rate of flow of water, and also of the absolute quantities. The meter itself is located in the engine room and is connected to the venturi throats by pipe lines. For accurate readings the pipe lines should be filled with water. Due to leaks and such it was found that the pipes have a tendency to collect air pockets, which if allowed to remain might materially effect the meter readings. The venturi proper is connected in series with the feed water line. During the calibration however, the boilers were fed thru a by-pass arrangement.

Water was pumped from the feed water heater thru the venturi, and weighed in a steel tank placed on a platform scale. This scale,

which was also used for weighing the coal and ash, was tested and found to be correct.
Since the capacity of the weighing tank was limited to slightly over 1000 pounds and because of the inability of the feed water pumps to maintain a constant pressure for any length of time it was found necessary to make short runs.
A study of the venturi meter itself shows that one division of the smallest integrating dial represented 1000 pounds; therefore, it was out of the question to use any of the integrated quantities for the short runs we must make.
Somewhat below the integration mechanism is a large dial of about a foot in diameter from which very accurate readings might be obtained. The hand of this large dial is connected, by a system of link motion, to the floats in the two mercury columns. The spaces above these two columns of mercury are connected to the pipe leads from the venturi; therefore, any difference in level between the two columns is a register of pressure difference or rate of flow. Thus when the

dial is properly calibrated it gives the rate of feeding the boiler in pounds per hour. During each run the water was sent thru the venturi and discharged into the weighing tank at a practically uniform rate of flow. A stop watch was employed to obtain a record of the time required for a definite amount of water to enter the tank and dividing rate by time gives actual rate. The rate as indicated by the venturi can be read and recorded. Therefore, knowing the ratio of the actual to the indicated rate of flow and assuming the integration to be correct, it is possible to plot a correction curve from which correct feed water data may be obtained.

Weight			Time		Feed water reading Pounds per Hour.	
Full	Tare	Water	Min.	Sec.	Actual	Venturi
1600	600	1000	11	11	5364	5000
1600	800	800	3	33	13500	12400
1750	800	950	3	47	13700	15060
1800	800	1000	7	47	7680	7700
1800	1000	800	1	51	25980	23400
1300	800	500	1	9	26100	22750
1400	900	500	1	0.5	2586	2250
1600	700	900	3	41	14940	13400
1400	700	700	2	41	15660	14400
1150	750	400	3	21	7200	6000
1650	1150	500	4	5	7350	6100
1400	700	700	3	28	12100	11000
1000	600	400	7	2	3416	3000
1600	1100	500	4	1	7470	6700


Venturi Calibration Curve.
25,000
20,000
15000
10,000
5000
0
Actual
Venturi
5000
10,000
15,000
20,000
25,000

Inspection of the observed data and of the calibration curve on page 10, show considerable discrepancy between actual and recorded readings. This error of the meter reading is due primarily to corrosion in the venturi, modified somewhat prehaps by a change in the conditions and amount of mercury. Also by an alteration of parts of the mechanism itself. The probabilities are however, that the error due to corrosion is the most important.

The steam gauge was next dismounted and tested under oil pressure. It was found to read consistently about 1-1/2 pounds too low. When the instrument is mounted, however, there is about a two pound head of water between the gauge and the water level in the boiler. The two pounds must be subtracted from the true reading at the gauge to get the actual steam pressure. The instrument in this condition will read one-half pound high. This error is negligible and the gauge reading considered correct.

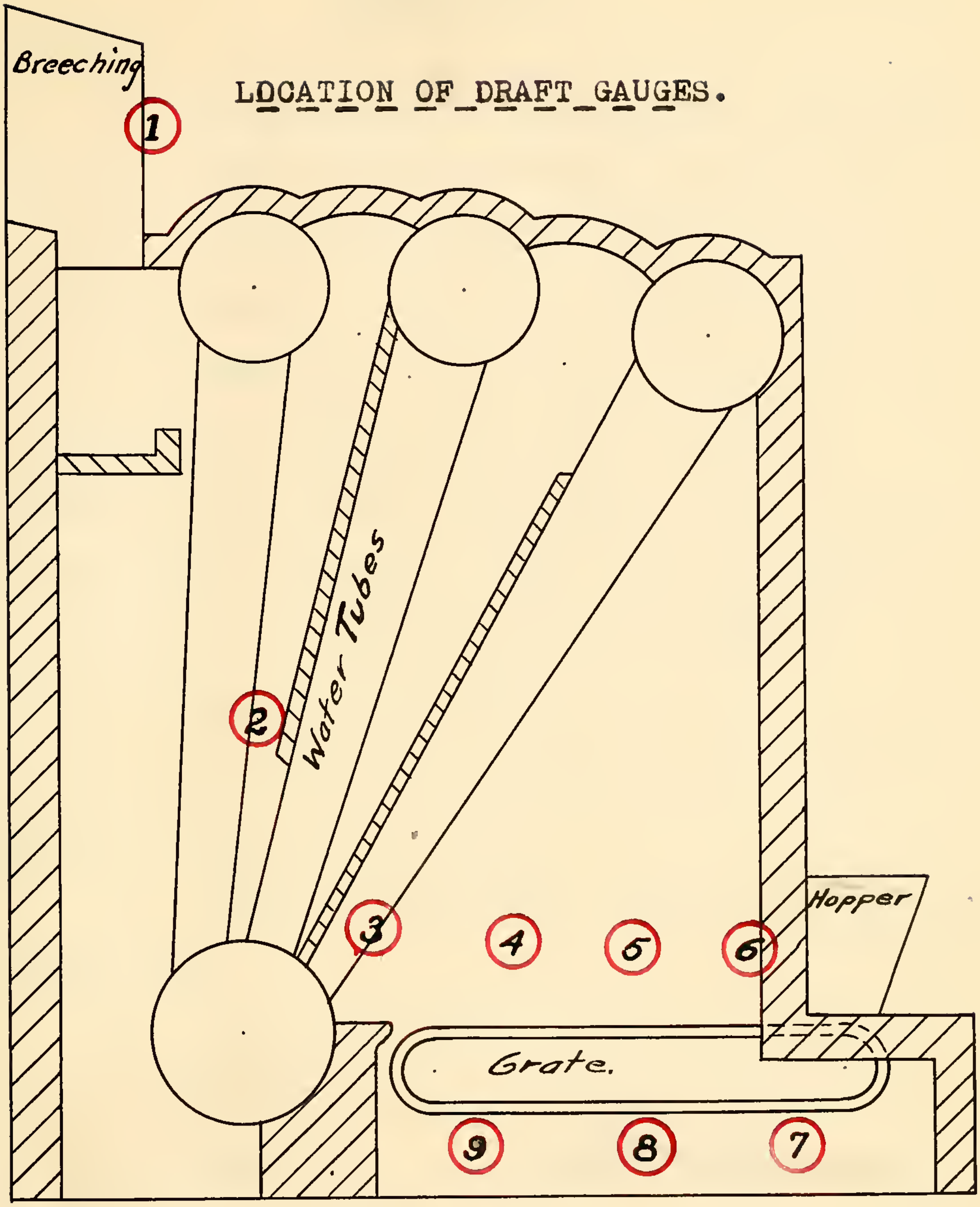
Correct temperature readings are generally important and need as great accuracy in recording as the pressures. Two recently calibrated thermometers were obtained from the Experimental Engineering Department and were used for the feed water and throttling calorimeter temperatures.

When a test on a boiler is made it is customary to obtain certain draft data which may be of value in locating boiler losses. For this purpose three different draft gauges were secured and after having been throughly cleaned were refilled with a colored kerosene solution of the proper density. The gauges were then rigidly mounted at suitable places on the outside wall of the boiler setting. The location of the points where draft readings were taken are shown on page 29. A tabulation of the data will be found on page 30.

In order to determine the quality of the steam, a throttling calorimeter was placed on the up-take pipe leading to the main header.

This point allowed only about 2-1/2 feet between the top of the boiler drum and where the sample of steam was taken and may bring in an error due to an excess of water mechanically carried over with the steam.

LOCATION OF DRAFT GAUGES.



Circles in red show location of draft readings and the numbers correspond to the numbers on page 30.

Manipulation.

Each run was made of eight hours duration and was started between the hours of nine and eleven. It is very important that the run be started properly. The boiler should be operating at the capacity to be tested for. In other words on a certain capacity run the boiler should be operated at this capacity for at least half an hour before the actual run is started. In this way the observations will be more constant and of greater value.

At the exact time of starting the following details must be observed.

1. Coal in the hopper must be at some known level.

2. Ash pit clean.

3. Steam pressure in boiler read.

4. Feed water reading of venturi taken from integrating dials.

Then at the end of the run the coal level, the water level in the boiler, and the steam pressure should all be the same as at the beginning of the run.

If the preceeding facts are followed out, the other necessary data will be sufficiently accurate if taken five or ten minutes after the test is started. During the test all coal put into the coal storage hopper is weighed on tested scales and from each unit quantity of coal added, a sample is taken for analysis. At the end of each hour the coal in the hopper is brought to the initial level and the weight of coal used in the hour recorded.

Readings of the following are made every fifteen minutes.

1. Venturi -(a) Integration dial record,
   (b) Rate of feeding boiler.
2. Feed water temperature.
3. Steam pressure.
4. Steam flow meter reding.
5. Temperature in throttling calorimeter.
6. Flue gas temperature.
7. Draft readings.

The venturi meter has already been discussed and the necessary readings are readily

made. The feed water temperature is obtained by a mercury thermometer inserted in an air filled recess in the feed water heater. This heater is of the open type.

The steam pressure is taken from the steam gauge mounted on the fireman's instrument board. The steam discharge flow meter gives a comparative record of the steam flow and is a valuable instrument to the fireman. It was our aim during the first five runs to maintain a fairly constant load by observing the flow meter readings. All the steam in excess of actual demands for power and heating was blown off into the atmosphere. A record of the steam flow meter readings was taken to check it with the feed water venturi meter. It was found that the steam meter would not record over 14,300# per hour although the dial was calibrated to 18,000# per hour. This was probably due to a loss of mercury in the instrument since by trial the dial was found to be free to move.

The object of the throttling calorimeter

is to determine the quality of the steam by observing the temperature of the superheat. This was done by means of a mercury bulb thermometer which was inserted into the oil pocket of the calorimeter.

The flue gas temperatures were obtained from a calibrated thermo-couple recorder. The thermo-couple was set into the center of the breeching.

Observations made at less frequent intervals were furnace temperatures and flue gas analyses. For low ratings the furnace temperatures were obtained by a thermo-couple thrust thru a fire door over the fire. For high ratings however this would not read the extreme temperatures and therefore a radiation pyrometer was used instead. Furnace temperatures were taken every hour.

The common type of Orsat apparatus was used for analyzing the flue gas. This apparatus gives the percent by volume of CO_2, O_2, and CO direct by removing these constituents one at a time from the sample.

The samples were taken thru an iron tube about one foot over the fire bed and a little in back of the hottest part of the fire. A sample was analyzed every half hour.

Other general observations made during each run were as follows.

1. Condition of the weather.
2. Damper position, (full, quarter or half open).
3. Draft doors, (open or closed).
4. Gases leaving stack, (clear or cloudy).
5. Outside temperature.
6. Boiler room temperature.
7. Barometer reading.

It was generally found more difficult to properly end a run than to begin one. This was due to the fact that the water level in the boiler and the steam pressure must be the same as when the run was started. This is necessarily true because not knowing the water content of the boiler at different water levels it is impossible to correct for difference in quantity or pressure. It takes careful manipulation of the

feed pumps and stoker engine to end the run properly. The venturi reading should be taken as soon as the run is finished so as to get a correct record of the feed water supplied. The man in charge of the coal must also see that the coal in the hopper is at the same level as when the run was started.

The ashes in the ash pit should be drawn as soon as the run is finished. They are weighed on the same scale that was used for the coal and a sample is also taken for analysis.

After all the data has been taken it is necessary to secure a suitable size sample of both coal and ash. From each basket of coal and ash handled a handful was taken as representitive of the contents of the basket. The resulting samples were too large to handle so they had to be reduced in size. To do this the sample was broken into smaller pieces and quartered. Then a fresh sample was taken by taking some from each quarter and this process was repeated until about a quart was left in finely crushed form.

The coal was analyzed each run for moisture, volatile matter, fixed carbon, and ash by means of the proximate method. After the whole sample had been ground to powder a test sample of about one half gram was weighed into a crucible of known weight. The sample was then placed into a thermstatically controlled oven at a constant temperature of 220° F. and the moisture driven off. At the end of an hour the crucible and sample were weighed and then returned to the oven. If upon a second weighing there was no appreciable loss in weight, the moisture was entirely removed and the loss in weight represented the amount of moisture in the sample. The volatile matter in the coal was driven off by heating it carefully over a bensun burner for about ten minutes. The loss in weight was the volatile matter. To test for the fixed carbon and ash the sample, or a fresh sample,was heated in the full flame of a blast lamp for a couple of hours. If the old sample was used the remaining substance is the ash and the loss in weight the

fixed carbon. If a fresh sample is used the fixed carbon is the loss in weight corrected for moisture and volatile matter driven off with it. The heating value of the coal was determined in a Junker Bomb calorimeter.

The ash sample is taken to test for the percent of combustible contained in the ash. This combustible either comes down into the ash pit inherent with the ash or in the form of coal that drops thru before it is burned. In testing the ash the sample must be throughly dried. This was done by placing a powdered sample in the same oven that was used for drying the coal. When all the moisture has been removed a sample of about one gram was weighed out into a crucible of known weight and placed over a blast lamp. The sample was heated in this way until all the combustible was driven off as shown by sucessive weighings of the crucible and sample. The loss in weight divided by the weight of the sample times 100 gives the percent of combustible in the ash. The average value for this in the

samples tested was 24% with a maximum value of 30%.

Organization of Data and Form of Calculations.

The results of the tests are outlined on the regular boiler test log sheets and the general scheme of calculation is as shown.

The following calculations are taken from the test made March 15, 1921.

Average results.

Steam gauge - - = 3595 ÷ 33 = 109#/sq.in.

Corrected - = 109 + 1 = 110# " "

Absolute - - = 110 + 15 = 125# " "

Draft at breeching = .625 - .005 = .620"

External air - - = 43° F.

Boiler room - - = 65° F.

Flue temperature - = 470° F.

Furnace temperature = 1730° F.

Feed water temperature = 213° F.

Steam temperature - = 345° F.

Fuel.

Coal as fired	= 55 x 212	= 11,670#
Dry coal consumed	= 11670x .9398	= 10,960#
Total dry refuse	= 23 x 45	= 1,035#
Percent dry refuse	= 1035 x 10830	= 9.53 %
Combustible consumed	= 10830 - 1035	= 9,795#

Percent combustible consumed

= 9795 ÷ 10830 = 90.40 %

Fuel per hour.

Coal as fired -	= 11,670 ÷ 8	= 1459# per hr.
Dry coal - -	= 10,830 ÷ 8	= 1354# per hr.
Combustible consumed	= 9,795 ÷ 8	= 1224# per hr.

Dry coal per square foot of grate surface

= 1,354 ÷ 70 = 19.34#

Total water.

Average throttling calorimeter temperature

= 7421 ÷ 31 = 240°F.

Quality of steam =

$$i = i'' - (1 - x)\, r_1$$

$$1162.8 = 1192.2 - (1 - x)\, 874.7$$

$$x = 96.6\%$$

Apparaant evaporation

= 414,100 - 331,200 = 82,900#

$(82,900 \times 12,100) \div 11,000$

$= 91,100\#$ corrected for venturi calibration.

Water actually evaporated into steam

$= 91,100 \times 96.6 = 88,100\#$

Factor of evaporation

$(xr + q - q_1) \div 970.4 = 1.010$

Total from and at 212°F.

$= 91,100 \times 1.01 = 92,000\#$

Water per hour.

Venturi indicated rate $356.4 \div 33 = 10.8$

$10.8 \times 1000 = 10,800\#$ per hr.

Calculated rate $= 91,100 \div 9 = 11,370\#$ per hr.

Actual evaporation to dry steam

$= 88,100 \div 8 = 11,010\#$ per hr.

Evaporation from and at 212°F.

$= 92,000 \div 8$ $11,500\#$ per hr.

Coal analysis.

Wt. of crucible - - - 8.7642 gms.

Wt. of crucible and moist coal 10.3022 gms.

Wt. of crucible and dry coal 10.2097 gms.

Wt. of crucible and fixed carbon 9.5590 gms.

Wt. of crucible and ash - 8.8782 gms.

Moisture .0925 gms. - 6.02%

V.C.M. .6507 gms. - 41.70%

Fixed carbon .6828 gms. - 44.30%

ASh .1120 gms. - 7.98%

Wt. of sample - - - 1.5380 gms.

Ash analysis.

Wt. of crucible - - - 9.4856 gms.

Wt. of crucible and dry ash - 11.7023 gms.

Wt. of ash - - - - 2.2167 gms.

Wt. of crucible and ash minus

the combustible - - 11.2331 gms.

Wt. of combustible - - 0.4692 gms.

Percen of combustible in ash 21.10 %

Cal. value per lb. of dry coal

$$= 12,700 + .9398 = 13,510 \text{ B.T.U.}$$

Cal. value per lb. of combustible

$$= 12,700 + .8600 = 14,780 \text{ B.T.U.}$$

Flue gas analysis

Sample	100 cc.	100 %
Carbon dioxide	7.3 cc.	7.3 %
Oxygen	10.24cc.	10.24%

Flue gas analyses for all tests

	CO_2	O_2	CO
March 15	7.30 %	10.24 %	-
March 24	6.02 %	7.99 %	-
March 28	7.43 %	10.02 %	-
March 29	7.25 %	12.19 %	-
March 31	8.63 %	9.70 %	0.54%
April 4	5.34 %	11.68 %	

Evaporation.

Apparant - = 91,100 ÷ 11,670 = 7.81#

Actual - - = 88,100 ÷ 11,670 = 7.55#

From and at 212° = 7.81 x 1.010 = 7.89#

Evaporation per pound of dry coal.

Apparant - = 7.81 ÷ .9398 = 8.30#

Actual - - = 7.55 ÷ .9398 = 8.04#

From and at 212° = 7.89 ÷ .9398 = 8.39#

Evaporation per sq. ft. of heating susface.

Actual - - = 11,010 ÷ 3500 = 3.15#

From and at 212° = 11,500 ÷ 3500 = 3.19#

Horse power.

H.P. - = 11,500 ÷ 34.5 = 333

Ratio - = 333 ÷ 350 = 0.95

Efficiency.

Heat absorbed per lb. of coal as fired

= 7.89 x 970.4 = 7,660 B.T.U.

Heat absorbed per lb. of dry coal

= 8.39 x 970.4 = 8,150 B.T.U.

Heat absorbed per lb. of combustible

= 9.26 x 970.4 = 9,000 B.T.U.

Efficiency of boiler and grate

$$=(7.89 \times 970.4) \div 12{,}700 = 60.3\ \%$$

Efficiency of boiler

$$= (9.26 \times 970.4) \div 14{,}780 = 61.0\ \%$$

Cost.

Cost per ton of coal - = \$ 5.50

Cost per 1000 lbs. of water from and at 212° F.

$$= \frac{1459 \times 1000 \times 550}{11010 \times 2000} = \$\ 0.349 = 34.9¢$$

DRAFT DATA.

Draft No.	Draft in inches of water.					
	March 15	March 24	March 28	March 29	March 31	April 4
1	0.312	0.325	0.356	0.354	0.320	0.288
2	.620	.635	.711	.685	.705	.570
3	.203	.218	.232	.234	.151	.174
4	.175	.188	.204	.204	.112	.174
5	.144	.113	.154	.166	.091	.148
6	.166	.096	.130	.172	.090	.169
7	.091	.066	.046	.055	-.150	.112
8	.034	.030	.022	.018	-.155	.032
9	.014	.017	.012	.014	-.142	.015

Note: Readings 7, 8, and 9 for March 31 are negative due to forced draft which caused a pressure under the grate.

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For

Date 3 / 15 / '21.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For ....

Date 3 / 15 / '21.

Duration of Trial,	hours.	8
Kind of Boiler, Stirling		-
Kind of Grate, Harrington		-
Grate Surface, length 7 ft., width 10 ft.	sq. ft.	70
Water Heating Surface,	sq. ft.	3500
Superheating Surface,	sq. ft.	-
Area, Chimney,	sq. ft.	54.8
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		50
AVERAGE PRESSURES		
Barometer,	ins. mercury.	29.45
Steam Gauge,	lbs. per sq. in.	110
Absolute Steam Pressure,	lbs. per sq. in.	125
Draught at Breeching,	ins. water.	0.620
AVERAGE TEMPERATURES		
External Air,	deg. F.	43
Boiler Room,	deg. F.	65
Flue,	deg. F.	470
Furnace,	deg. F.	1730
Feed Water,	deg. F.	213
Steam,	deg. F.	344.4
TOTAL FUEL		
Coal as Fired,	lbs.	11,670
Dry Coal Consumed,	lbs.	10,960
Total Refuse, Dry,	lbs.	1,035
Total Refuse, Dry,	per cent of dry coal.	9.06
Combustible, Consumed,	lbs.	9925
Combustible, Consumed,	per cent of dry coal.	90.4
FUEL PER HOUR		
Coal as Fired,	lbs.	1459
Dry Coal,	lbs.	1354
Combustible, Consumed,	lbs.	1224
Dry Coal, per sq. foot of Grate	lbs.	19.34
TOTAL WATER		
Quality of Steam,	per cent.	96.6
Apparently Evaporated,	lbs.	91,100
Actually Evaporated into Dry Steam,	lbs.	88,100
Factor of Evaporation,		1.01
Total from and at 212°,	lbs.	92,000
WATER PER HOUR		
Apparently Evaporated,	lbs.	11,380
Actually Evaporated into Dry Steam,	lbs.	11,010
Evaporated from and at 212°,	lbs.	11,500

ANALYSIS OF FUEL AS FIRED			
Fixed Carbon,	44.30	per cent.	
Volatile Matter,	41.69	per cent.	
Moisture,	6.02	per cent.	
Ash,	7.98	per cent.	
Combustible,	86.00	per cent.	
Calorific Value per lb. of Fuel as Fired,		B. T. U.	12700
Calorific Value per lb. of Dry Fuel,		B. T. U.	13510
Calorific Value per lb. of Combustible,		B. T. U.	14780
EVAPORATION			
PER POUND OF FUEL AS FIRED			
Apparent,	7.81	lbs.	
Actual,	7.55	lbs.	
Equivalent from and at 212°,	9.36	lbs.	
PER POUND DRY COAL			
Apparent,	8.41	lbs.	
Actual,	8.13	lbs.	
Equivalent from and at 212°,	10.10	lbs.	
PER POUND OF COMBUSTIBLE, CONSUMED			
Apparent,	9.32	lbs.	
Actual,	8.98	lbs.	
Equivalent from and at 212°	11.16	lbs.	
PER SQ. FOOT WATER HEATING SURFACE PER HOUR			
Actual,	3.15	lbs.	
Equivalent from and at 212°,	3.90	lbs.	
HORSE POWER			
On basis 34½ lbs. equiv. evap. per hour,		H. P.	396
Builders Rating,		H. P.	350
Ratio of Commercial to Builders Rating			1.132
EFFICIENCY			
Heat Absorbed per lb. of coal as fired,		B. T. U.	9060
Heat Absorbed per lb. dry coal,		B. T. U.	9800
Heat Absorbed per lb. of Combustible *Consumed,*		B. T. U.	10840
Efficiency of Boiler and Grate,		per cent.	71.3
Efficiency of Boiler,		per cent.	73.2
COST OF EVAPORATING WATER			
Cost of Coal, Dollars per ton,	$5.50		
Cost of Evap. 1,000 lbs. of Water from and at 212°,			34.9¢

Weather:-cold and clear

West draft door open.
Damper wide open.

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For *Date* 3 / 24 / '21.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For ________________ *Date* 3 / 24 / '21.

Duration of Trial,	hours.	8
Kind of Boiler, Stirling		-
Kind of Grate, Harrington		-
Grate Surface, length 7 ft., width 10 ft.	sq. ft.	70
Water Heating Surface,	sq. ft.	3500
Superheating Surface,	sq. ft.	-
Area, Chimney,	sq. ft.	54.8
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		50

AVERAGE PRESSURES

Barometer,	ins. mercury.	19.07
Steam Gauge,	lbs. per sq. in.	105
Absolute Steam Pressure,	lbs. per sq. in.	120
Draught at Breeching,	ins. water.	0.635

AVERAGE TEMPERATURES

External Air,	deg. F.	50
Boiler Room,	deg. F.	77
Flue,	deg. F.	471
Furnace,	deg. F.	1870
Feed Water,	deg. F.	207
Steam,	deg. F.	341.3

TOTAL FUEL

Coal as Fired,	lbs.	12,050
Dry Coal Consumed,	lbs.	11,430
Total Refuse, Dry,	lbs.	1,100
Total Refuse, Dry,	per cent of dry coal.	9.61
Combustible, Consumed,	lbs.	10,330
Combustible, Consumed,	per cent of dry coal.	90.30

FUEL PER HOUR

Coal as Fired,	lbs.	1506
Dry Coal,	lbs.	1416
Combustible, Consumed,	lbs.	1291
Dry Coal, per sq. foot of Grate	lbs.	20.20

TOTAL WATER

Quality of Steam,	per cent.	96.7
Apparently Evaporated,	lbs.	97,200
Actually Evaporated into Dry Steam,	lbs.	93,990
Factor of Evaporation,		1.012
Total from and at 212°,	lbs.	98,370

WATER PER HOUR

Apparently Evaporated,	lbs.	12,150
Actually Evaporated into Dry Steam,	lbs.	11,750
Evaporated from and at 212°,	lbs.	12,280

ANALYSIS OF FUEL AS FIRED

Fixed Carbon,	46.25	per cent.	
Volatile Matter,	41.70	per cent.	
Moisture,	5.03	per cent.	
Ash,	7.02	per cent.	
Combustible,	84.95	per cent.	
Calorific Value per lb. of Fuel as Fired,		B. T. U.	12850
Calorific Value per lb. of Dry Fuel,		B. T. U.	13520
Calorific Value per lb. of Combustible,		B. T. U.	14610

EVAPORATION

PER POUND OF FUEL AS FIRED

Apparent,	8.06	lbs.
Actual,	7.80	lbs.
Equivalent from and at 212°,	8.16	lbs.

PER POUND DRY COAL

Apparent,	8.50	lbs.
Actual,	8.22	lbs.
Equivalent from and at 212°,	8.60	lbs.

PER POUND OF COMBUSTIBLE, CONSUMED

Apparent,	9.40	lbs.
Actual,	9.10	lbs.
Equivalent from and at 212°	9.52	lbs.

PER SQ. FOOT WATER HEATING SURFACE PER HOUR

Actual,	3.36	lbs.
Equivalent from and at 212°,	3.51	lbs.

HORSE POWER

On basis 34½ lbs. equiv. evap. per hour,	H. P.	356
Builders' Rating,	H. P.	350
Ratio of Commercial to Builders Rating		1.015

EFFICIENCY

Heat Absorbed per lb. of coal as fired,	B. T. U.	7910
Heat Absorbed per lb. dry coal,	B. T. U.	8350
Heat Absorbed per lb. of Combustible *Consumed*,	B. T. U.	9250
Efficiency of Boiler and Grate,	per cent.	60.9
Efficiency of Boiler,	per cent.	63.2

COST OF EVAPORATING WATER

Cost of Coal, Dollars per ton,	$5.50
Cost of Evap. 1,000 lbs. of Water from and at 212°,	33.7¢

Weather:- warm and rainy

Draft Doors

West door open 10:00- 12:50

Both doors open12:50- 6:00

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For *Date* 3 / 28 / '21.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For ______ *Date* 3 / 28 / '21.

Duration of Trial,	hours.	8
Kind of Boiler, Stirling		-
Kind of Grate, Harrington		-
Grate Surface, length 7 ft., width, 10 ft.	sq. ft.	70
Water Heating Surface,	sq. ft.	3500
Superheating Surface,	sq. ft.	-
Area, Chimney,	sq. ft.	54.8
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		50
AVERAGE PRESSURES		
Barometer,	ins. mercury.	30.10
Steam Gauge,	lbs. per sq. in.	107
Absolute Steam Pressure,	lbs. per sq. in.	122
Draught at Breeching,	ins. water.	0.71
AVERAGE TEMPERATURES		
External Air,	deg. F.	27
Boiler Room,	deg. F.	70
Flue,	deg. F.	470
Furnace,	deg. F.	1960
Feed Water,	deg. F.	213
Steam,	deg. F.	342.5
TOTAL FUEL		
Coal as Fired,	lbs.	12,150
Dry Coal Consumed,	lbs.	11,320
Total Refuse, Dry,	lbs.	13.05
Total Refuse, Dry,	per cent of dry coal.	11.52
Combustible, Consumed,	lbs.	10,015
Combustible, Consumed,	per cent of dry coal.	89.50
FUEL PER HOUR		
Coal as Fired,	lbs.	1518
Dry Coal,	lbs.	1415
Combustible, Consumed,	lbs.	1252
Dry Coal, per sq. foot of Grate	lbs.	20.2
TOTAL WATER		
Quality of Steam,	per cent.	96.5
Apparently Evaporated,	lbs.	114,200
Actually Evaporated into Dry Steam,	lbs.	110,200
Factor of Evaporation,		1.010
Total from and at 212°,	lbs.	115,340
WATER PER HOUR		
Apparently Evaporated,	lbs.	14,275
Actually Evaporated into Dry Steam,	lbs.	13,700
Evaporated from and at 212°,	lbs.	14,410

ANALYSIS OF FUEL AS FIRED			
Fixed Carbon,	39.42	per cent.	
Volatile Matter,	47.52	per cent.	
Moisture,	6.61	per cent.	
Ash,	6.45	per cent.	
Combustible,	86.94	per cent.	
Calorific Value per lb. of Fuel as Fired,		B. T. U.	12150
Calorific Value per lb. of Dry Fuel,		B. T. U.	13000
Calorific Value per lb. of Combustible,		B. T. U.	13900
EVAPORATION			
PER POUND OF FUEL AS FIRED			
Apparent,	9.40	lbs.	
Actual,	9.06	lbs.	
Equivalent from and at 212°,	9.49	lbs.	
PER POUND DRY COAL			
Apparent,	10.10	lbs.	
Actual,	9.73	lbs.	
Equivalent from and at 212°,	10.20	lbs.	
PER POUND OF COMBUSTIBLE, CONSUMED			
Apparent,	11.41	lbs.	
Actual,	11.00	lbs.	
Equivalent from and at 212°	11.51	lbs.	
PER SQ. FOOT WATER HEATING SURFACE PER HOUR			
Actual,	3.94	lbs.	
Equivalent from and at 212°,	4.12	lbs.	
HORSE POWER			
On basis 34½ lbs. equiv. evap. per hour,		H. P.	418
Builders Rating,		H. P.	350
Ratio of Commercial to Builders Rating			1.19
EFFICIENCY			
Heat Absorbed per lb. of coal as fired,		B. T. U.	9220
Heat Absorbed per lb. dry coal,		B. T. U.	11200
Heat Absorbed per lb. of Combustible *Consumed*,		B. T. U.	9900
Efficiency of Boiler and Grate,		per cent.	75.8
Efficiency of Boiler,		per cent.	80.4
COST OF EVAPORATING WATER			
Cost of Coal, Dollars per ton,			$ 5.50
Cost of Evap. 1,000 lbs. of Water from and at 212°,			29.0¢

Weather:- cold, clear, & windy.

Draft doors open.

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For

Date 3 / 29 / '21.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For

Date 3 / 29 / '21.

Duration of Trial,	hours.	8
Kind of Boiler, Stirling		-
Kind of Grate, Harrington		-
Grate Surface, length 7 ft., width 10 ft.	sq. ft.	70
Water Heating Surface,	sq. ft.	3500
Superheating Surface,	sq. ft.	-
Area, Chimney,	sq. ft.	54.8
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		50
AVERAGE PRESSURES		
Barometer,	ins. mercury.	28.70
Steam Gauge,	lbs. per sq. in.	104
Absolute Steam Pressure,	lbs. per sq. in.	118
Draught at Breeching,	ins. water.	0.685
AVERAGE TEMPERATURES		
External Air,	deg. F.	40
Boiler Room,	deg. F.	65
Flue,	deg. F.	480
Furnace,	deg. F.	1330
Feed Water,	deg. F.	213.5
Steam,	deg. F.	240
TOTAL FUEL		
Coal as Fired,	lbs.	13,100
Dry Coal Consumed,	lbs.	12,180
Total Refuse, Dry,	lbs.	1510
Total Refuse, Dry,	per cent of dry coal.	12.41
Combustible, Consumed,	lbs.	10,670
Combustible, Consumed,	per cent of dry coal.	87.5
FUEL PER HOUR		
Coal as Fired,	lbs.	1637
Dry Coal,	lbs.	1522
Combustible, Consumed,	lbs.	1334
Dry Coal, per sq. foot of Grate	lbs.	21.77
TOTAL WATER		
Quality of Steam,	per cent.	95.8
Apparently Evaporated,	lbs.	123,500
Actually Evaporated into Dry Steam,	lbs.	118,300
Factor of Evaporation,		1.010
Total from and at 212°,	lbs.	124,700
WATER PER HOUR		
Apparently Evaporated,	lbs.	15,430
Actually Evaporated into Dry Steam,	lbs.	14,780
Evaporated from and at 212°,	lbs.	15,580

ANALYSIS OF FUEL AS FIRED			
Fixed Carbon,	50.20	per cent.	
Volatile Matter,	34.53	per cent.	
Moisture,	7.07	per cent.	
Ash,	8.20	per cent.	
Combustible,	84.73	per cent.	
Calorific Value per lb. of Fuel as Fired,		B. T. U.	12000
Calorific Value per lb. of Dry Fuel,		B. T. U.	12920
Calorific Value per lb. of Combustible,		B. T. U.	14170
EVAPORATION			
PER POUND OF FUEL AS FIRED			
Apparent,	9.42	lbs.	
Actual,	9.11	lbs.	
Equivalent from and at 212°,	9.52	lbs.	
PER POUND DRY COAL			
Apparent,	10.13	lbs.	
Actual,	9.71	lbs.	
Equivalent from and at 212°,	10.22	lbs.	
PER POUND OF COMBUSTIBLE, CONSUMED			
Apparent,	11.59	lbs.	
Actual,	11.10	lbs.	
Equivalent from and at 212°	11.69	lbs.	
PER SQ. FOOT WATER HEATING SURFACE PER HOUR			
Actual,	4.23	lbs.	
Equivalent from and at 212°,	4.45	lbs.	
HORSE POWER			
On basis 34½ lbs. equiv. evap. per hour,		H. P.	452
Builders Rating,		H. P.	350
Ratio of Commercial to Builders Rating			1.29
EFFICIENCY			
Heat Absorbed per lb. of coal as fired,		B. T. U.	9250
Heat Absorbed per lb. dry coal,		B. T. U.	9910
Heat Absorbed per lb. of Combustible *Consumed*,		B. T. U.	11340
Efficiency of Boiler and Grate,		per cent.	77.7
Efficiency of Boiler,		per cent.	80.0
COST OF EVAPORATING WATER			
Cost of Coal, Dollars per ton,			$ 5.50
Cost of Evap. 1,000 lbs. of Water from and at 212°,			28.9¢

Weather:- Cool and rainy.

West draft door open.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For *Date* 3 / 31 / '21.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For

Date 3 / 31 / '21.

Duration of Trial,	hours.	8
Kind of Boiler, Stirling'		-
Kind of Grate, Harrington		-
Grate Surface, length 7 ft., width 10 ft.	sq. ft.	70
Water Heating Surface,	sq. ft.	3500
Superheating Surface,	sq. ft.	-
Area, Chimney,	sq. ft.	54.8
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		50
AVERAGE PRESSURES		
Barometer,	ins. mercury.	29.62
Steam Gauge,	lbs. per sq. in.	113.3
Absolute Steam Pressure,	lbs. per sq. in.	128
Draught at Breeching,	ins. water.	0.795
AVERAGE TEMPERATURES		
External Air,	deg. F.	43.5
Boiler Room,	deg. F.	63
Flue,	deg. F.	506
Furnace,	deg. F.	1400
Feed Water,	deg. F.	206
Steam,	deg. F.	346.2
TOTAL FUEL		
Coal as Fired,	lbs.	17,300
Dry Coal Consumed,	lbs.	16,140
Total Refuse, Dry,	lbs.	1738
Total Refuse, Dry,	per cent of dry coal.	10.77
Combustible, Consumed,	lbs.	14,402
Combustible, Consumed,	per cent of dry coal.	89.2
FUEL PER HOUR		
Coal as Fired,	lbs.	2162
Dry Coal,	lbs.	2 017
Combustible, Consumed,	lbs.	1800
Dry Coal, per sq. foot of Grate	lbs.	28.8
TOTAL WATER		
Quality of Steam,	per cent.	97.2
Apparently Evaporated,	lbs.	142,300
Actually Evaporated into Dry Steam,	lbs.	138,200
Factor of Evaporation,		1.021
Total from and at 212°,	lbs.	145,290
WATER PER HOUR		
Apparently Evaporated,	lbs.	17780
Actually Evaporated into Dry Steam,	lbs.	17,270
Evaporated from and at 212°,	lbs.	18,160

ANALYSIS OF FUEL AS FIRED				
Fixed Carbon,	43.20	per cent.		
Volatile Matter,	42.87	per cent.		
Moisture,	6.65	per cent.		
Ash,	7.28	per cent.		
Combustible,	86.07	per cent.		
Calorific Value per lb. of Fuel as Fired,			B. T. U.	12400
Calorific Value per lb. of Dry Fuel,			B. T. U.	13290
Calorific Value per lb. of Combustible,			B. T. U.	14410
EVAPORATION				
PER POUND OF FUEL AS FIRED				
Apparent,	8.24	lbs.		
Actual,	7.99	lbs.		
Equivalent from and at 212°,	8.39	lbs.		
PER POUND DRY COAL				
Apparent,	8.83	lbs.		
Actual,	8.57	lbs.		
Equivalent from and at 212°,	9.01	lbs.		
PER POUND OF COMBUSTIBLE, CONSUMED				
Apparent,	9.88	lbs.		
Actual,	9.58	lbs.		
Equivalent from and at 212°	10.09	lbs.		
PER SQ. FOOT WATER HEATING SURFACE PER HOUR				
Actual,	4.94	lbs.		
Equivalent from and at 212°,	5.19	lbs.		
HORSE POWER				
On basis 34½ lbs. equiv. evap. per hour,			H. P.	527
Builders Rating,			H. P.	350
Ratio of Commercial to Builders Rating				1.50
EFFICIENCY				
Heat Absorbed per lb. of coal as fired,			B. T. U.	8150
Heat Absorbed per lb. dry coal,			B. T. U.	8750
Heat Absorbed per lb. of Combustible *Consumed*,			B. T. U.	9780
Efficiency of Boiler and Grate,			per cent.	65.6
Efficiency of Boiler,			per cent.	68.0
COST OF EVAPORATING WATER				
Cost of Coal, Dollars per ton,				$ 5.50
Cost of Evap. 1,000 lbs. of Water from and at 212°,				32.8¢

Weather:- Cool and windy.

West draft door open.

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For ______ *Date* 4 / 4 / '21.

Mechanical Engineering Laboratory

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test Made At Armour Institute of Technology

For ....

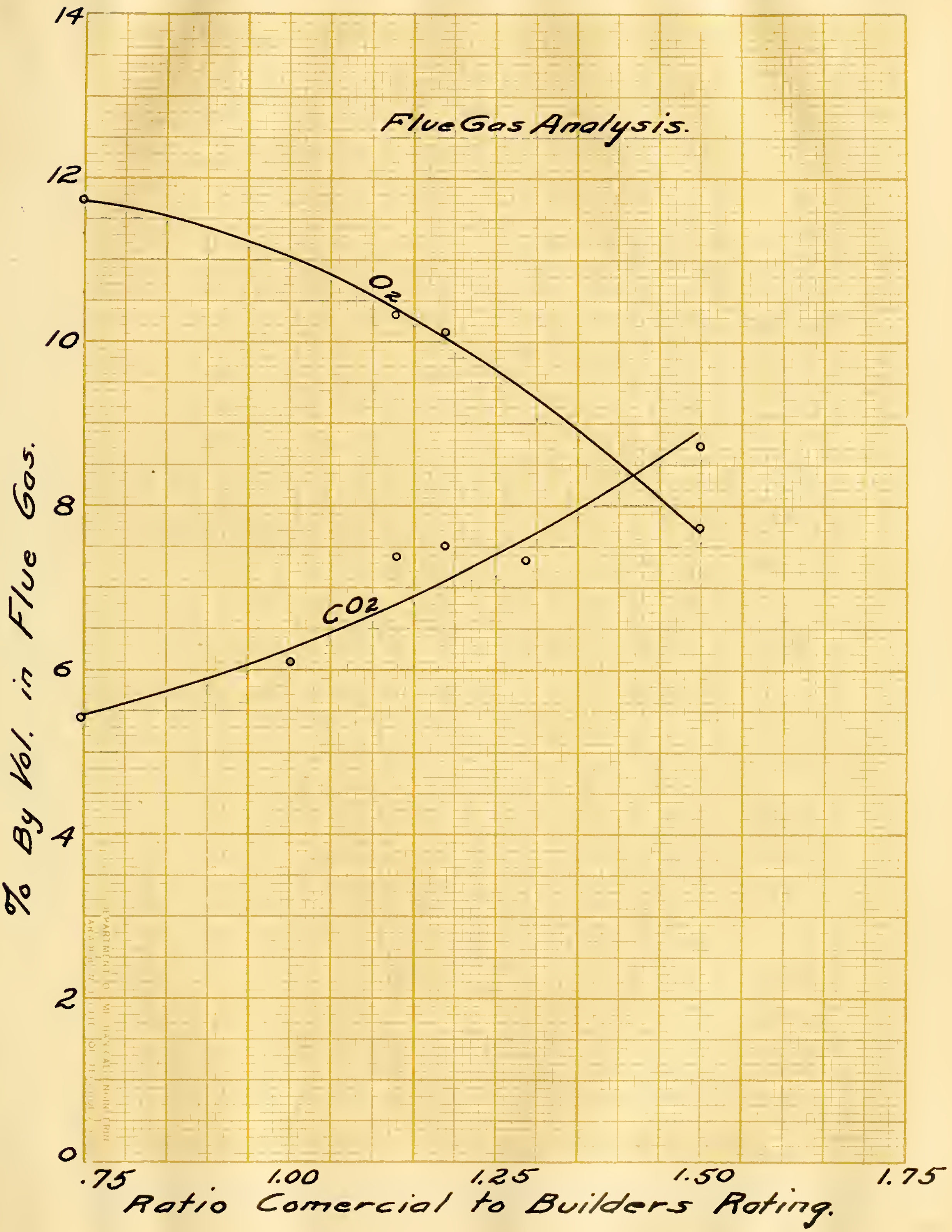
Date 4 / 4 / '21.

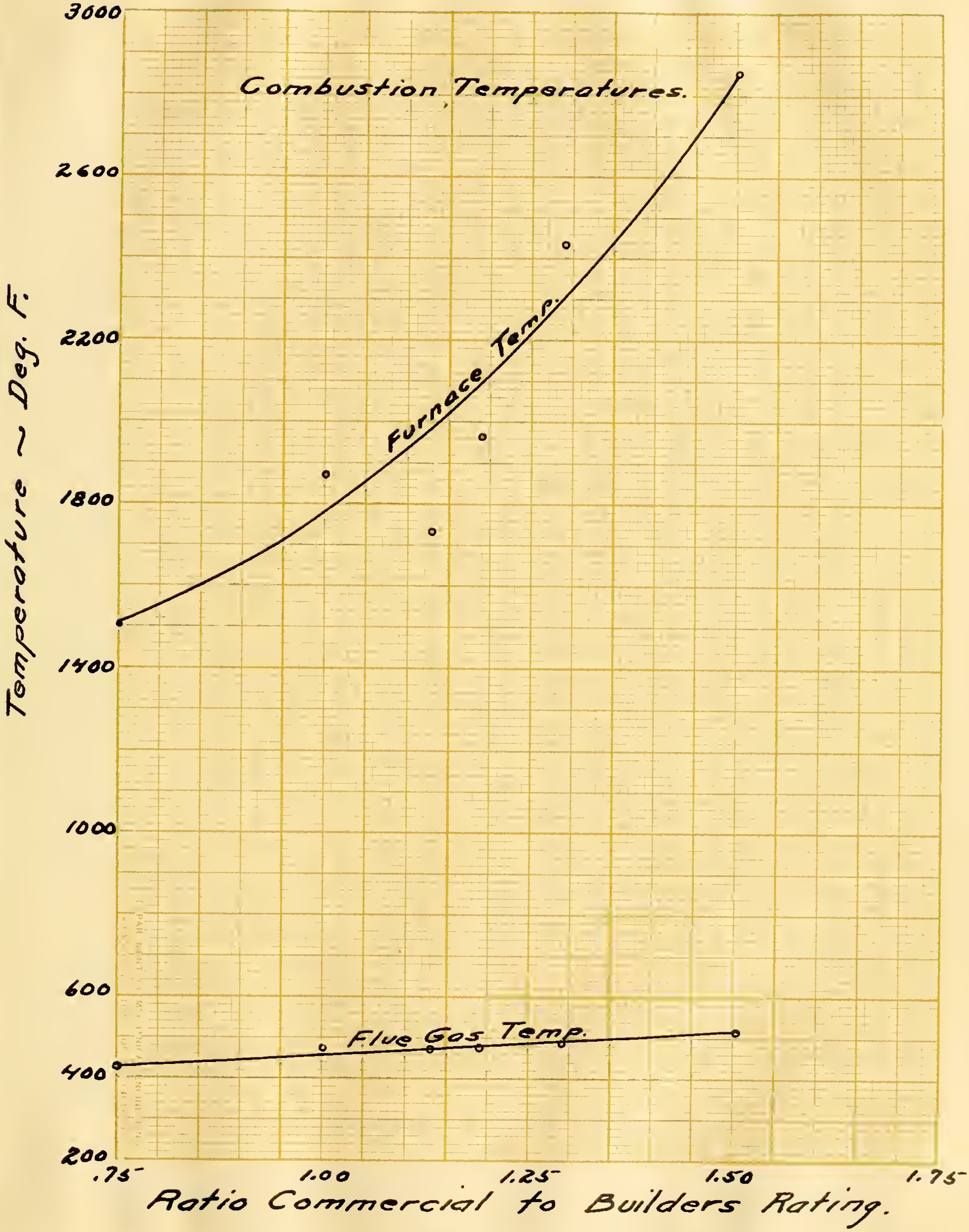
Duration of Trial,	hours.	8
Kind of Boiler, Stirling		-
Kind of Grate, Harrington		-
Grate Surface, length 7 ft., width, 10 ft.	sq. ft.	70
Water Heating Surface,	sq. ft.	3500
Superheating Surface,	sq. ft.	-
Area, Chimney,	sq. ft.	54.8
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		50
AVERAGE PRESSURES		
Barometer,	ins. mercury.	29.63
Steam Gauge,	lbs. per sq. in.	108.2
Absolute Steam Pressure,	lbs. per sq. in.	123
Draught at Breeching,	ins. water.	0.570
AVERAGE TEMPERATURES		
External Air,	deg. F.	80
Boiler Room,	deg. F.	92
Flue,	deg. F.	422
Furnace,	deg. F.	1300
Feed Water,	deg. F.	194
Steam,	deg. F.	343.2
TOTAL FUEL		
Coal as Fired,	lbs.	7,700
Dry Coal Consumed,	lbs.	7,150
Total Refuse, Dry,	lbs.	725
Total Refuse, Dry,	per cent of dry coal.	10.12
Combustible, Consumed,	lbs.	6,426
Combustible, Consumed,	per cent of dry coal.	89.9
FUEL PER HOUR		
Coal as Fired,	lbs.	962
Dry Coal,	lbs.	894
Combustible, Consumed,	lbs.	804
Dry Coal, per sq. foot of Grate	lbs.	12.78
TOTAL WATER		
Quality of Steam,	per cent.	96.1
Apparently Evaporated,	lbs.	68,500
Actually Evaporated into Dry Steam,	lbs.	65,830
Factor of Evaporation,		1.024
Total from and at 212°,	lbs.	70,150
WATER PER HOUR		
Apparently Evaporated,	lbs.	8,560
Actually Evaporated into Dry Steam,	lbs.	8,220
Evaporated from and at 212°,	lbs.	8,770

ANALYSIS OF FUEL AS FIRED			
Fixed Carbon,	45.71	per cent.	
Volatile Matter,	40.43	per cent.	
Moisture,	7.04	per cent.	
Ash,	6.82	per cent.	
Combustible,	87.14	per cent.	
Calorific Value per lb. of Fuel as Fired,		B. T. U.	12300
Calorific Value per lb. of Dry Fuel,		B. T. U.	13220
Calorific Value per lb. of Combustible,		B. T. U.	14100
EVAPORATION			
PER POUND OF FUEL AS FIRED			
Apparent,	8.91	lbs.	
Actual,	8.55	lbs.	
Equivalent from and at 212°,	9.11	lbs.	
PER POUND DRY COAL			
Apparent,	9.58	lbs.	
Actual,	9.22	lbs.	
Equivalent from and at 212°,	9.81	lbs.	
PER POUND OF COMBUSTIBLE, CONSUMED			
Apparent,	10.67	lbs.	
Actual,	10.25	lbs.	
Equivalent from and at 212°	10.91	lbs.	
PER SQ. FOOT WATER HEATING SURFACE PER HOUR			
Actual,	2.35	lbs.	
Equivalent from and at 212°,	2.51	lbs.	
HORSE POWER			
On basis 34½ lbs. equiv. evap. per hour,		H. P.	254
Builders Rating,		H. P.	350
Ratio of Commercial to Builders Rating			.725
EFFICIENCY			
Heat Absorbed per lb. of coal as fired,		B. T. U.	8840
Heat Absorbed per lb. dry coal,		B. T. U.	9520
Heat Absorbed per lb. of Combustible *Consumed*,		B. T. U.	10600
Efficiency of Boiler and Grate,		per cent.	71.8
Efficiency of Boiler,		per cent.	75.0
COST OF EVAPORATING WATER			
Cost of Coal, Dollars per ton,			$ 5.50
Cost of Evap. 1,000 lbs. of Water from and at 212°,			30.2¢

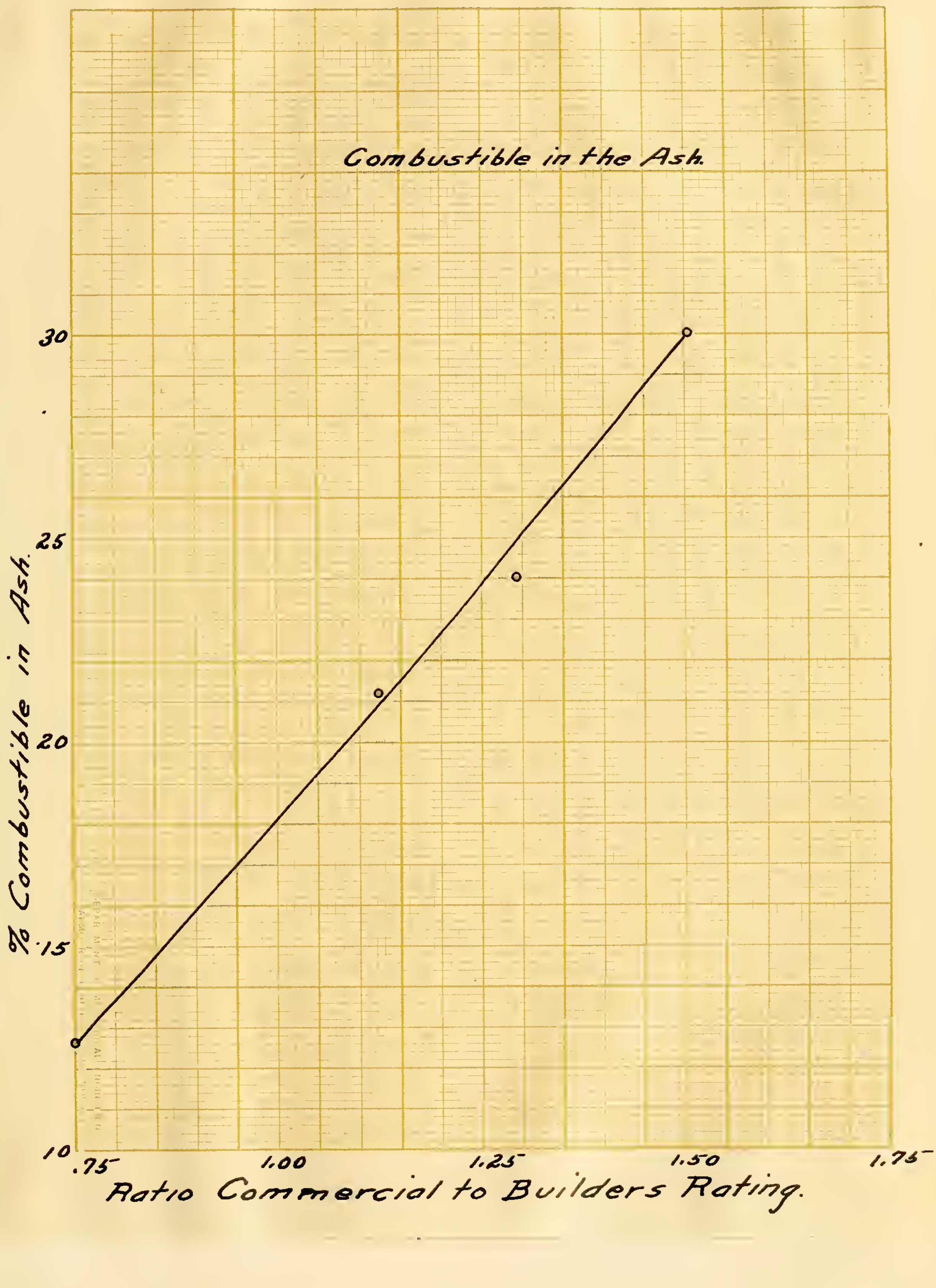
Weather:- Warm and clear.

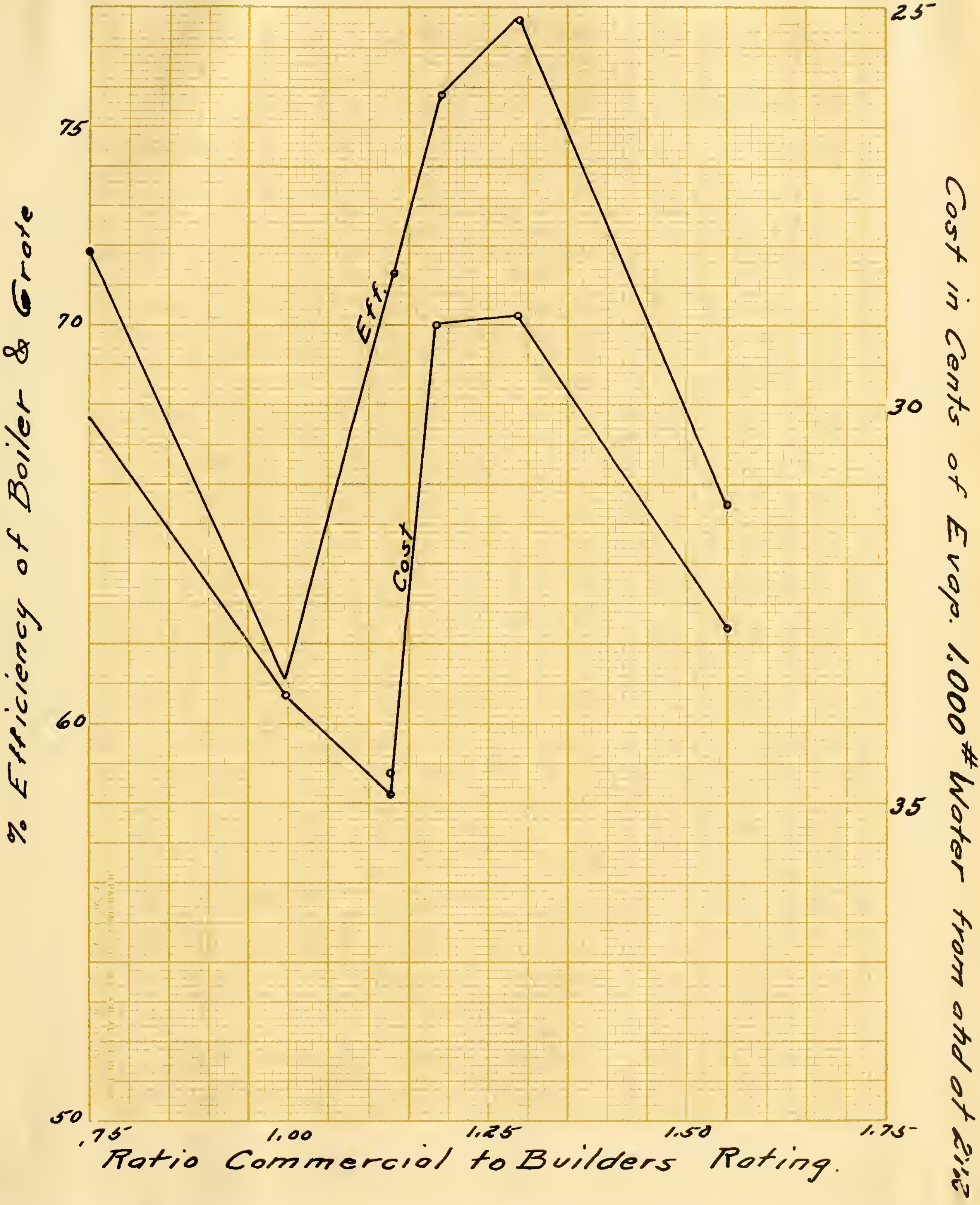
Both draft doors closed


Flue Gas Analysis.
O2
CO2
% By Vol. in Flue Gas.
14
12
10
8
6
4
2
0
.75
1.00
1.25
1.50
1.75
Ratio Comercial to Builders Rating.



Combustion Temperatures.
Furnace Temp.
Flue Gas Temp.
Temperature ~ Deg. F.
3000
2600
2200
1800
1400
1000
600
400
200
.75
1.00
1.25
1.50
1.75
Ratio Commercial to Builders Rating.


Combustible in the Ash.
30
25
20
15
10
% Combustible in Ash.
.75
1.00
1.25
1.50
1.75
Ratio Commercial to Builders Rating.



% Efficiency of Boiler & Grate
Cost in Cents of Evap. 1.000# Water from and at 212°
Eff.
Cost
75
70
60
50
25
30
35
.75
1.00
1.25
1.50
1.75
Ratio Commercial to Builders Rating.

Discussion.

An inspection of the results obtained in this series of tests brings out many interesting points for discussion and also several pronounced inconsistencies. There is too great a difference in efficiencies for practically the same load conditions. A study and analysis of the probabilities of error is a help to better understand the value of the data.

There are two great classes of errors, namely accumulative and compensating. The weighing of the coal, though a simple process, may be the source of considerable error. Close observation generally showed a tendency on the part of some to over-load each basket, therby making this error decidedly accumulative. It may be assumed that readings from gauges, thermometers, etc are generally observed and recorded correctly.

Whether or not an eight hour run is sufficiently accurate depends on the degree of care required. For general commercial purposes

this length of run should be sufficient. For extreme accurcy a twentyfour hour run makes the error due to difference in fire bed condition before and after the test negligible. This error even for short runs is comparatively small and may be neglected.

In boiler testing of extreme accuracy all recording instruments for feed water measurements should be discarded and the feed water actually weighed. In this way all guess work is eliminated and with it one of the chief sources of error in efficiency tests. However if a high grade type of venturi meter is used it should be tested under exact operating conditions and immediately preceeding the test. In this way only can the calibration curve be made of much value.

It is a simple matter to make the necessary coal and ash analyses, but it is certainly a difficult and uncertain task to select a representative sample. The method of quartering as previously outlined is recognized as being satisfactory and is so for all general purposes, but nevertheless it may introduce a

error. Many testing engineers analyze the coal for moisture and ash and compute the heating value by assuming a certain number of B.T.U. per pound of combustible. For Illinois coal 14,300 B.T.U. per pound of combustible is used.

In all the runs there appeared to be a lack of scientific operation of the boiler, which if overcome might lead to greater efficiency. The damper leading to the stack was always wide open and from the flue gas analyses except in the forced draft run, there was found to be considerable air excess. The feed water pumps instead of operating in accordance with the demand for steam were sometimes at their highest speed and then again idling. It has been stated in practical power journals that such intermittent feeding to the boiler might cause the efficiency to drop as much as 5 percent. What has been said of the feed water pumps applies also to the stoker engine.

The highest capacities obtained during the runs were 452 H.P. or 129% rating under

natural draft and 527 H.P. or 150% rating with forced draft. This appears to be poor operation when we consider that central power stations can run their boilers from 300% to 350% rating. In conducting the forced draft run the blower was atarted about an hour before the beginning of the run and the boiler brought up to as high a capacity as possible. Thruout the run the depth of fire bed was maintained at 9 inches, (the greatest possible with this installation) and the fire carried back almost as far as the bridge wall. Observation of the draft data showed that the pressure under the fire was practically negligible proving that the condition of the fire bed was not suitable. In order to increase the resistance of the fire bed the depth of coal must be increased or a smaller mesh coal used. The coal that was used thru out the tests was washed nut #3. For satisfactory forced draft operation screenings are generally suitable.

The dense smoke produced under high rates of combustion was evidence of too small a combustion chamber which prevented a through mixing of the gases before striking the tube surfaces. The flue gas temperatures were not especially low. The lowest average temperature obtained for a run was 470° F. which is fairly good for a small installation. For the forced draft test the flue gas temperature went to over 500° F. which is quite high.

The average percent of combustible in the ash was only 24 which gave a loss of combustible of only a little over 1 percent. This is very good practice and speaks well for the stoker.

As a whole the results were quite satisfactory and represent far better operation than the average small power plant. The tests were all made under actual operating conditions and the plant was not tuned up to give results that are not obtained in actual practice.